



# Spatial Management in Fisheries

## Lessons from Empirical Bioeconomics



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Prepared for  
NMFS/NOAA Spatial Modeling Fisheries Economics Workshop  
October 22, 2002

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## Four Key Phrases

- Spatial Closure
- Marine Reserve
- Marine Protected Area (MPA)
- No-take (harvest) Zones

## Key Questions

- Are marine reserves a good idea for fisheries management?
- If so, under what conditions?
- What are the implications of ignoring fisher behavior?

## Biological Justifications

- Rebuild overexploited areas
- Take advantage of dispersal mechanisms (e.g. sink/source patterns)
- Returns to scale in organism size and population density
- Preserve natural life cycle
- Hedge against stock collapse

# Economic Skepticism

- Reserves do not necessarily address the fundamental driving force of overexploitation - open access
- Could be more costly than other forms of management
- Whatever happened to equimarginality?

# A Realistic Synthesis

Biological arguments throw a wrench into our typical economic modeling efforts (e.g. convex production sets). Predicting the ultimate consequences of reserves requires empirical bioeconomic modeling.

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## Catch Improvement Conjecture

Marine reserves may generate  
aggregate harvest increases

## Preview of Findings

- Marine reserves are unlikely to increase harvest in the fishery described below
- Most biological modeling of reserves has resulted in overly optimistic predictions about their performance
- The magnitude and spatial distribution of fishing effort before and after reserve formation are key



# Empirical Setting

## Northern California Red Sea Urchin Fishery

- Uni
- Daily diving trips
- Uniform harvest technology
- About 135 owner-operators
- Data combine logbooks and landings tickets (and weather buoy data) from 1988-97
- Marine reserves under consideration

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## California Sea Urchins: Ideal for Spatial Management?

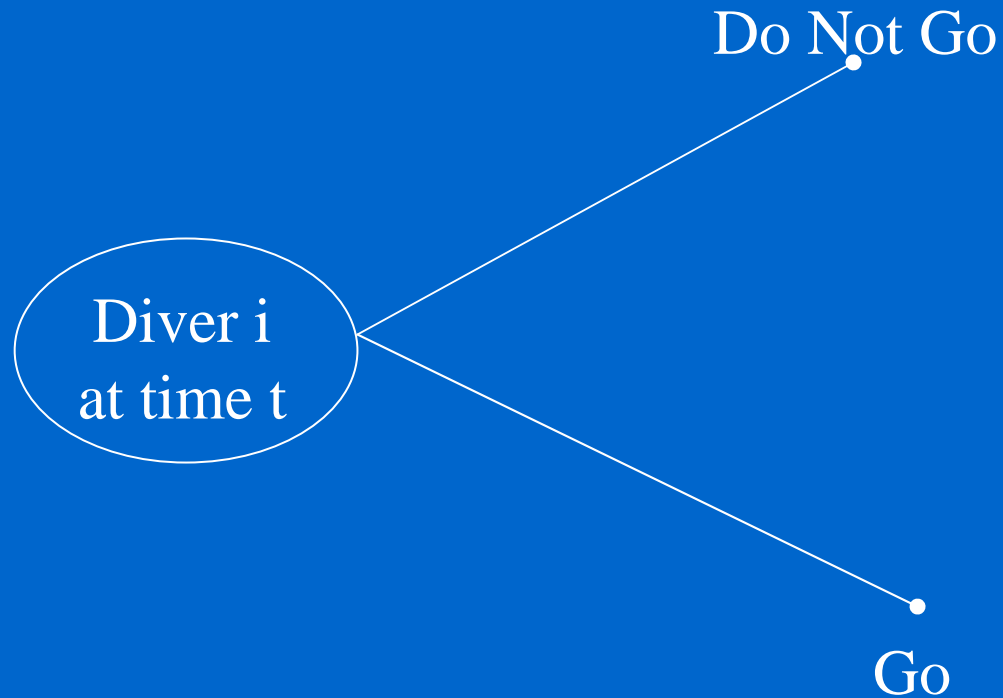
- The resource is “patchy” – has potential for sinks and sources
- Subpopulations connected via larval dispersal, sedentary adults
- Density-dependent reproduction
- Fecundity returns to scale (in organism size)
- CPUE has shown dramatic declines

# Structure of the Economic Model:

## 3 Decision Layers

- Daily discrete participation choice
  - Fish or not

# Daily Participation



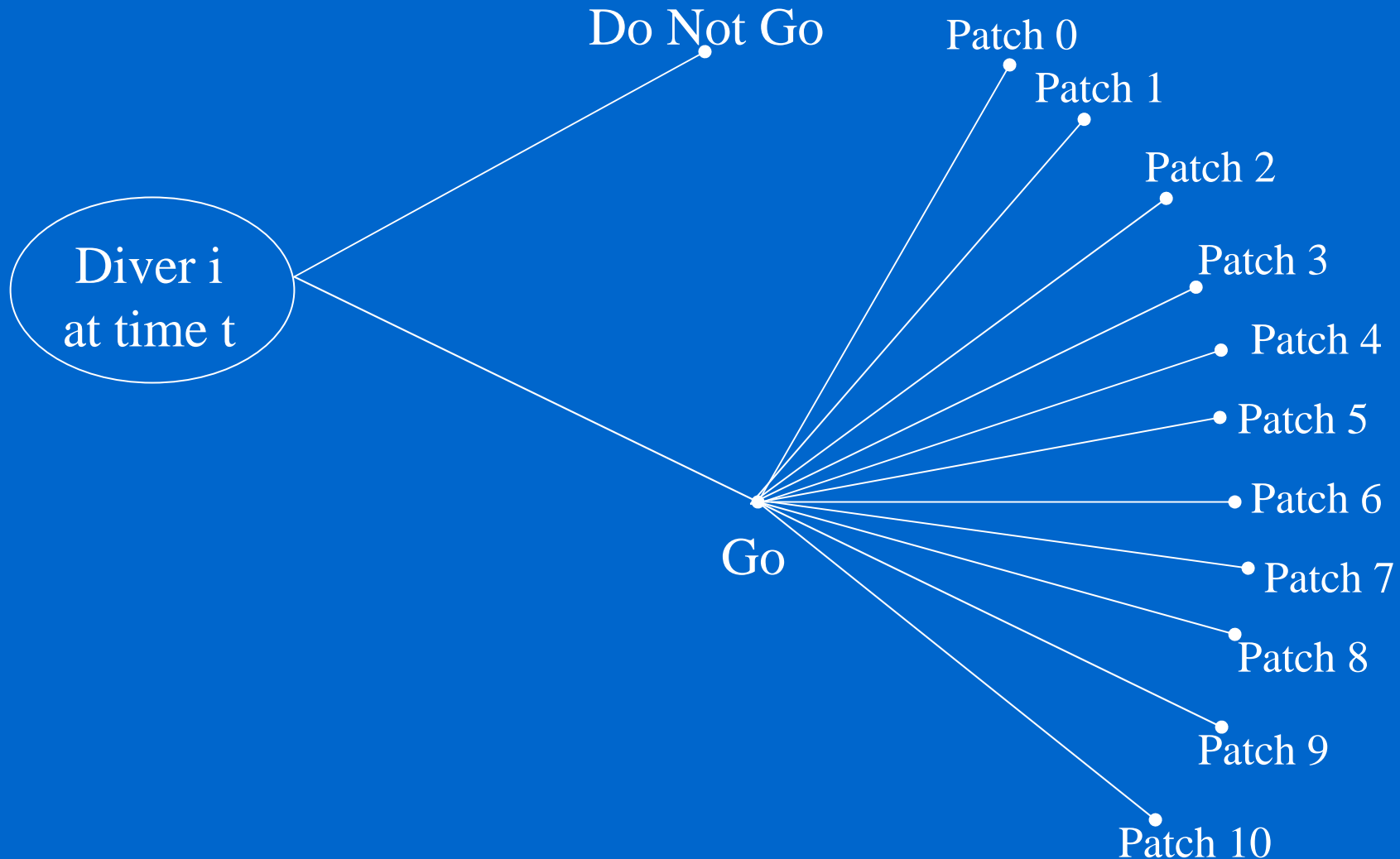
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## Structure of the Economic Model:

### 3 Decision Layers

- Daily discrete participation choice
  - Fish or not
- Location choice
  - If fish, choose a patch or fishing ground

# Daily Participation and Location Choice





## Empirical Strategy



Repeated Nested Logit for  
Participation and Location Choice  
Branches

## Participation and Location Results

- Spatial pattern of exploitation is not uniform and is responsive to economic conditions
- Higher revenues and shorter travel distances increase fishing in a patch
- Higher revenues increase participation
- Participation also driven by institutional characteristics and weather conditions

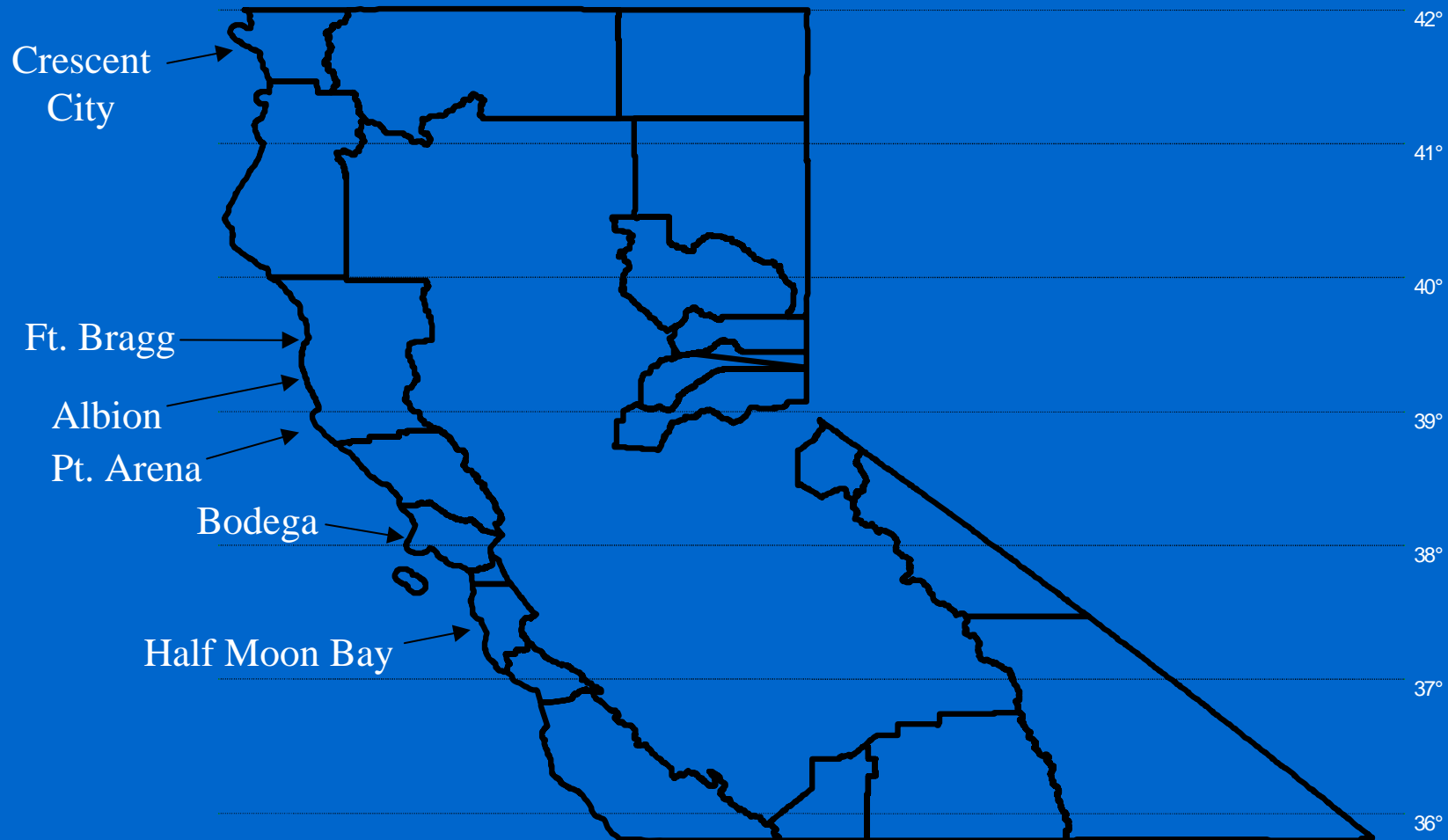


# Structure of the Economic Model:

## 3 Decision Layers

- Daily discrete participation choice
  - Fish or not
- Location choice
  - If fish, choose a patch or fishing ground
- Port switching
  - Within Northern California
  - Between Northern and Southern California

# Northern California Ports





# Empirical Strategy



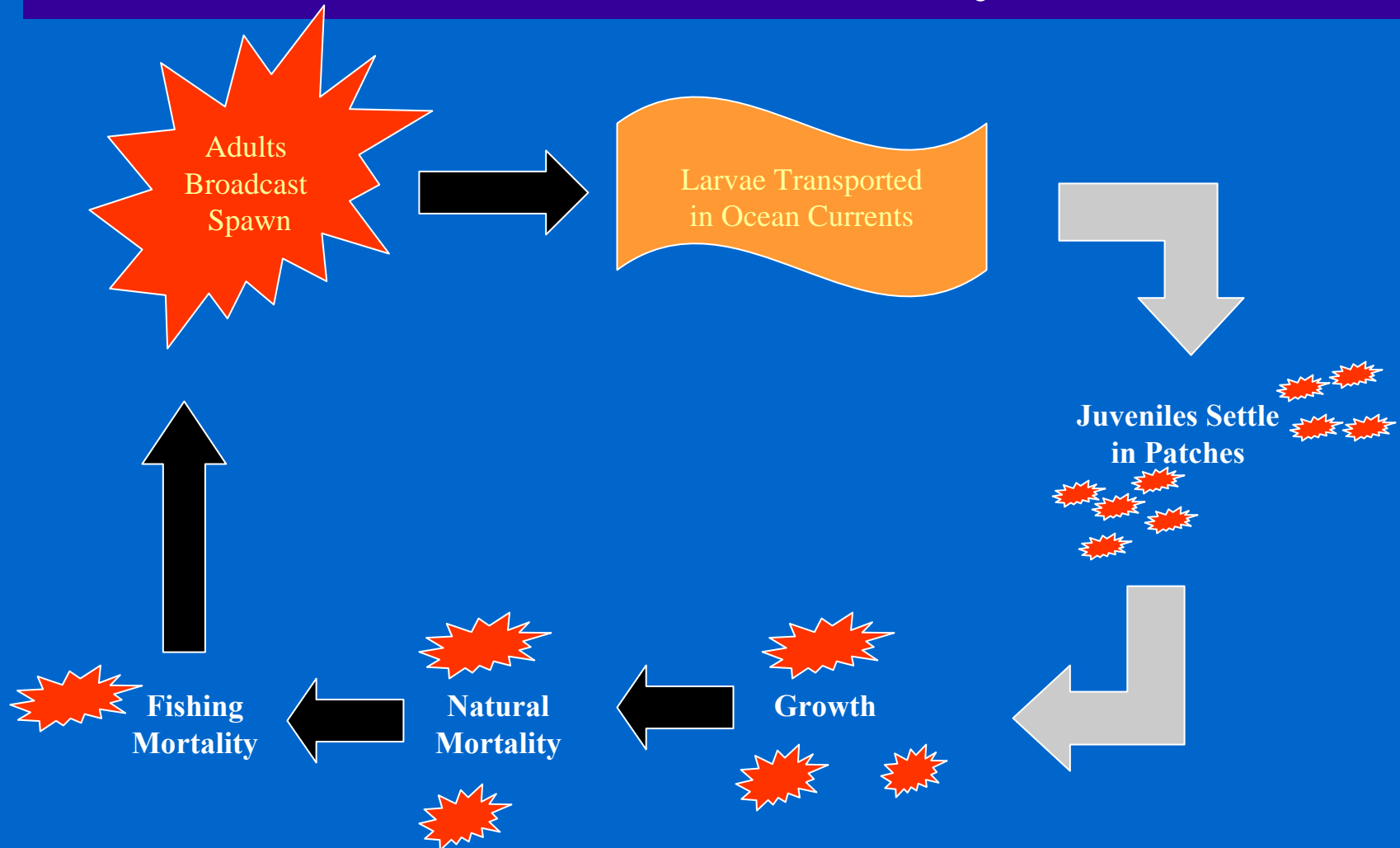
SUR share models



## Port Switching Results

- Port shares respond to revenue differences across space
- Shares respond sluggishly; there are time lags involved
- The speed of adjustment differs across share models
  - more immediate across ports within northern California
  - slower for switches between northern and southern California

# The Sea Urchin Life Cycle



# Structure of the Biological Model

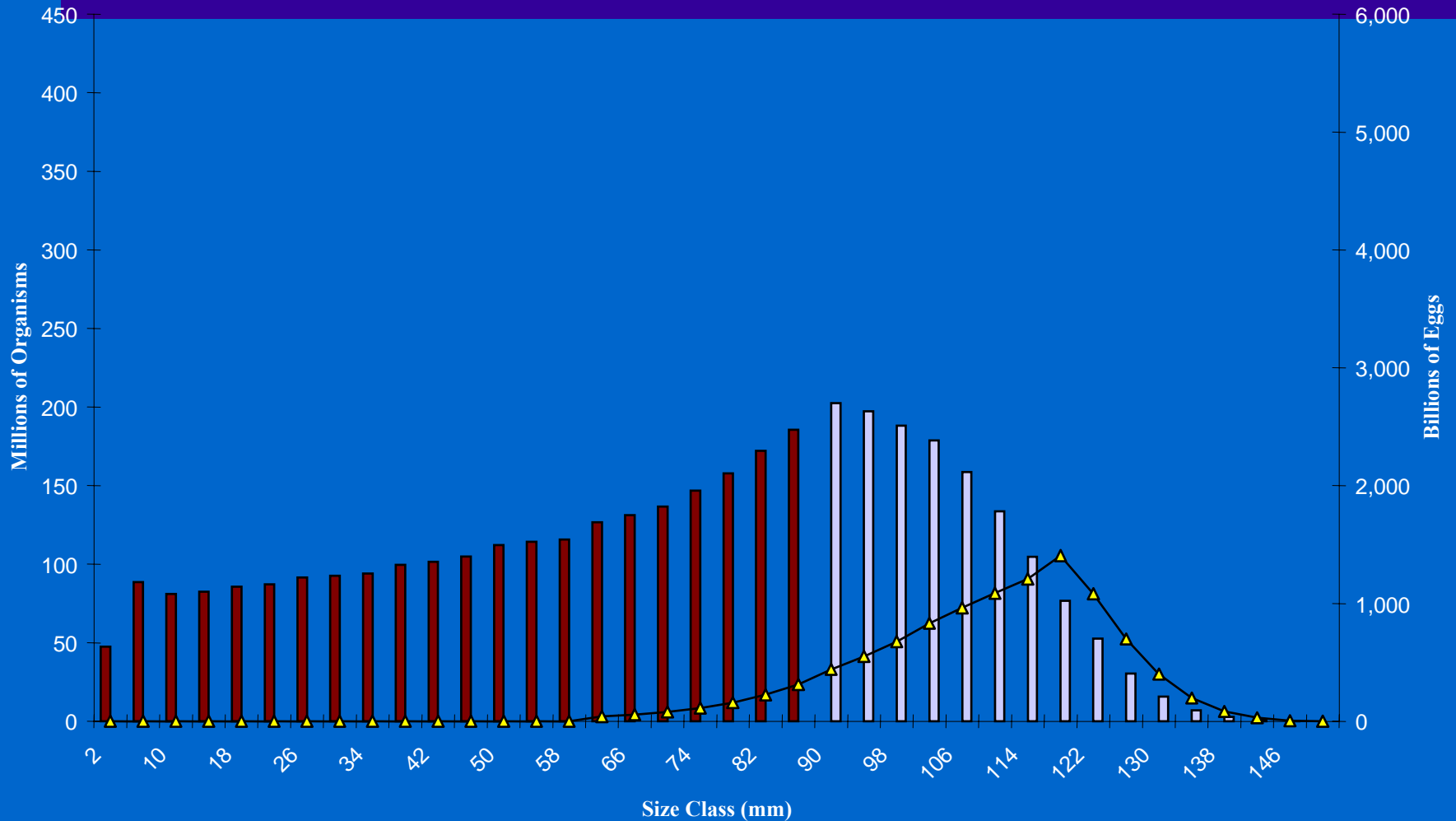
- Age- and size-structured metapopulation.
- Fecundity as a function of urchin size is increasing at an increasing rate
- Discrete subpopulations linked through larval dispersal
- The size limit combined with growth and allometric parameters convert number of organisms in each age/size class into patch-specific harvestable biomass

# The Bioeconomic Link

- Catch in each patch as a function of fishing effort and harvestable biomass
- Biomass dynamics evolve according to the metapopulation model and catch
- Resource abundance feeds back into expected revenues
- Spatially explicit fishing effort predictions feed back into catch in the next period

# Steady-State Size Distribution and Egg Production

## Patch 8 when Fished



Organisms Below the Size Limit

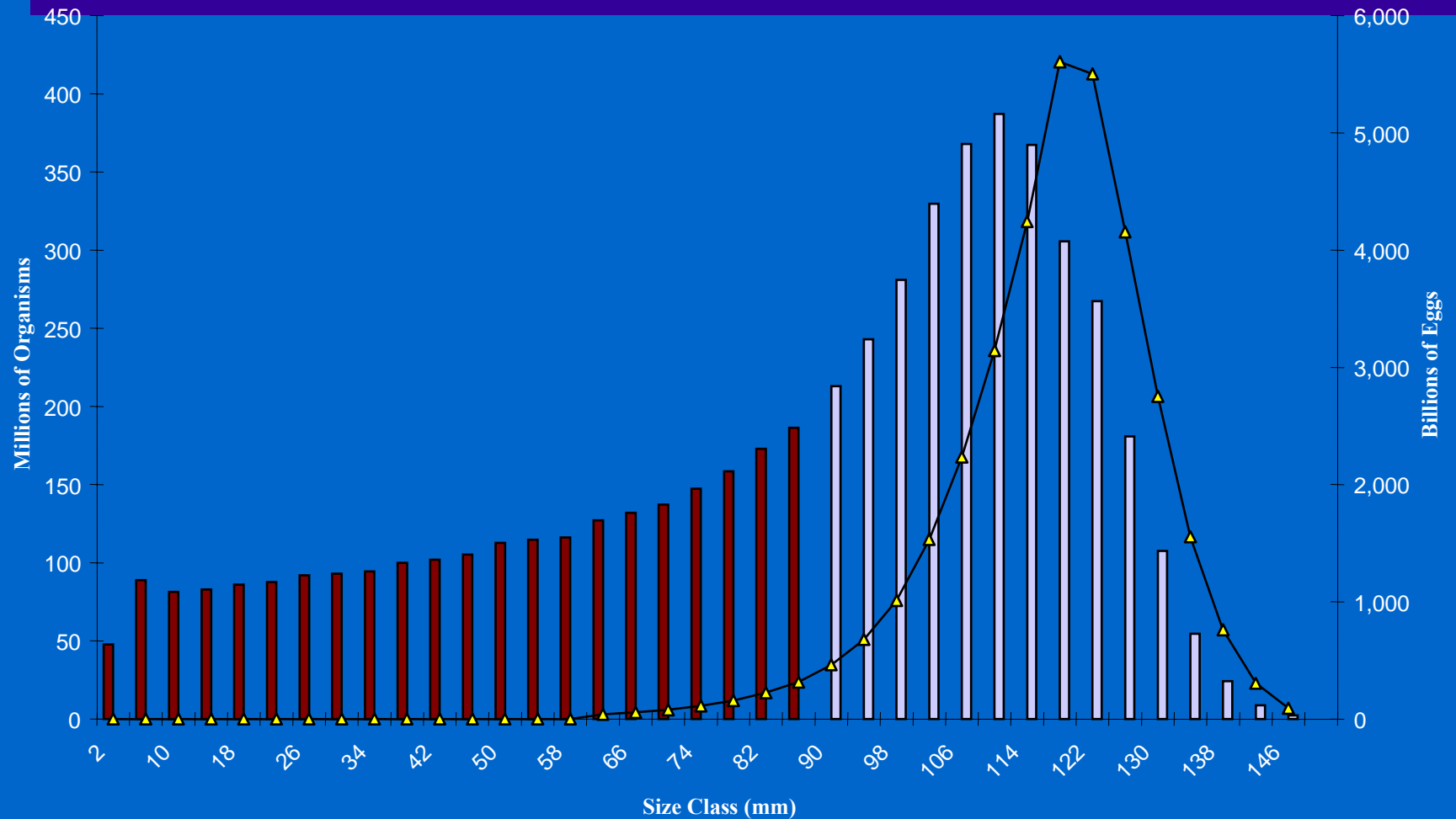
Organisms Above the Size Limit

Egg Production from Size Class



# Steady-State Size Distribution and Egg Production

## Patch 8 when Closed



Organisms Below the Size Limit

Organisms Above the Size Limit

Egg Production from Size Class

## Two Issues to Explore

- Best prediction for performance of a marine reserve
- Implications for ignoring behavioral responses
  - ECON versus NOECON

# Marine Reserves and Economic Behavior

	Steady-State Harvest (1,000 pounds)	Steady-State Egg Production (Billions)	Discounted* Revenues (\$1000)
<u>With Discrete Choice ECON</u>			
No Closure	830	1,316	17,440
Close Patch 8	752	1,441	15,074
<u>With No Economic Model - NOECON Steady-state Calibration</u>			
No Closure	829 **	434	17,400
Close Patch 8	868	553	16,423
<u>With No Economic Model - NOECON Approach Path Calibration</u>			
No Closure	386 ***	267	8,096
Close Patch 8	545	397	8,204

\* Uses a 5% constant discount rate and assumes \$1 per pound of sea urchin.

\*\* Calibrated steady-state harvest to behavioral model.

\*\*\* Calibrated approach path catch to actual catch.

# Economics of Marine Reserves with Macroeconomic Shocks

		Steady-State N. California Divers	Trips Per Diver Per Year	Partic Rate	Steady-State Harvest (1,000 pounds)	Steady-State Egg Production (Billions)	Discounted* Revenues (\$1000)
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## Discrete Choice Only

No Closure	131	29.9	13%	830	1,316	17,440
Close Patch 8	131	25.3	11%	752	1,441	15,074

## Port Choice and Discrete Choice

No Closure	33	57.8	25%	638	1,627	13,400
Close Patch 8	36	47.2	20%	576	1,692	11,660

## Port Choice and Discrete Choice - 50% Decrease in S. Cal. Revenues

No Closure	83	37.9	16%	802	1,399	16,846
Close Patch 8	89	31.2	13%	728	1,495	14,683

## Discrete Choice Only

*Double prices and exogenous increase in participation rate*

No Closure	131	107.1	46%	883	720	18,548
Close Patch 8	131	96.5	41%	921	879	17,362

## Port Choice and Discrete Choice

*75% Decrease in S. Cal. Revenues, double prices, and exogenous increase in participation rate*

No Closure	56	174.5	75%	972	796	20,402
Close Patch 8	68	143.1	61%	952	910	18,865

\* Uses a 5% constant discount rate and assumes \$1 per pound of sea urchin.

# Conclusions

- Both **magnitude** and the **spatial pattern** of fishing effort influence the performance of reserves
- Fixed effort assumption at high levels of exploitation on the approach path drives marine reserve optimism
- Assumption of uniformly distributed effort at high levels of exploitation also drives marine reserve optimism
- A realistic depiction of reserves that includes behavioral responses along the approach path to the steady-state leads to far more pessimism
- It is essential to distinguish between two types of externalities - excess fishing effort and an inefficient spatial allocation



## Discussion



As a policy instrument for controlling fishing effort, a marine reserve is an extreme policy.



# Appendix A



## Statistical Models and Results

# Statistical Model of Partic. And Loc.

$$U_{ijt} = v_{ijt} + \varepsilon_{ijt}$$

$$= f(\mathbf{X}_{it}, \mathbf{Z}_{i1t}, \mathbf{Z}_{i2t}, \dots, \mathbf{Z}_{iMt}; \boldsymbol{\theta}) + \varepsilon_{ijt},$$

$$Pr(\text{Go to } j) = \frac{\exp\left\{\frac{\mathbf{z}_{jt}'\boldsymbol{\gamma}}{(1-\sigma)} + \mathbf{x}_t'\boldsymbol{\beta} + (1-\sigma)I\right\}}{\sum_{k=0}^{10} \left[ \exp\left\{\frac{\mathbf{z}_{kt}'\boldsymbol{\gamma}}{(1-\sigma)}\right\} + \exp\left\{\frac{\mathbf{z}_{kt}'\boldsymbol{\gamma}}{(1-\sigma)} + \mathbf{x}_t'\boldsymbol{\beta} + (1-\sigma)I\right\} \right]}$$

$$\begin{aligned} Pr(\text{Do not go}) &= 1 - \sum_{k=0}^{10} Pr(\text{Go to } k) \\ &= \frac{1}{1 + \exp[\mathbf{x}_t'\boldsymbol{\beta} + (1-\sigma)I]} \end{aligned}$$

$$\text{where } I = \ln \left[ \sum_{k=0}^{10} \exp\left\{\frac{\mathbf{z}_{kt}'\boldsymbol{\gamma}}{(1-\sigma)}\right\} \right]$$



## Nested Logit Estimates

### Not Location-Specific

Variable	Coefficient	Standard Error	Z - statistic
Constant	1.06	0.048	22.21
WP	-0.18	0.005	-34.69
WS	-0.11	0.003	-36.69
WH	-0.74	0.011	-70.36
DWEEK	-0.74	0.012	-60.02

### Location-Specific

Variable	Coefficient	Standard Error	Z - statistic
DISTANCE	-7.27	0.036	-203.72
ER	0.08	0.001	65.17
$\sigma$	0.22	0.027	8.34

Log-likelihood	-189,878
Observations	401151
Pseudo $R^2$ (1)	0.21
Pseudo $R^2$ (2)	0.81

Pseudo  $R^2$  (1) is based on the log-likelihood in a Conditional Logit Model with choice-specific constants.

Pseudo  $R^2$  (2) is based on the log-likelihood of  $n \cdot \ln(1/J)$ , where  $J = 12$  possible choices.

# Statistical Model of Port Switching

*An SUR Partial Adjustment Approach*

$$s_{mt}^* = f^m(\Pi_t, \dots, \Pi_t; \theta_{m1}, \dots, \theta_{mM}), \quad m = 1, \dots, M$$

$$s_{mt} - s_{mt-1} = (1 - \lambda)(s_{mt}^* - s_{mt-1}) + \varepsilon_{mt}, \quad m = 1, \dots, M$$

$$s_{mt} = \lambda s_{mt-1} + (1 - \lambda)f^m(\Pi_t, \dots, \Pi_t; \theta_{m1}, \dots, \theta_{mM}) + \varepsilon_{mt}$$

## Estimating Equation

$$s_{mt} = (1 - \lambda)\alpha_m + \lambda s_{mt-1} + (1 - \lambda)\sum_{k=1}^M \gamma_{mk} \ln(R_{kt}) + \varepsilon_{mt}$$

Restrictions:  $\sum_{m=1}^M \gamma_{mk} = 0$   $\frac{\sum_{m=1}^M \alpha_m}{(1 - \lambda)} = 1$

## South/North Switching OLS Model of Port Shares

Variable	Parameter	Coefficient	t-statistic
Constant	$\alpha$	0.028061	0.151
Lagged SOC Share	$\lambda$	0.861212	17.242 **
$\ln(R_{SOC})$	$\gamma_{SOC}$	0.056192	1.6678 *
$\ln(R_{NOC})$	$\gamma_{NOC}$	-0.050767	-1.908 *
$R^2$	0.8231		
n	111		

\*\* indicates significant at the 5% level and \* indicates the 10% level.

# The Metapopulation Model

$$Size_{j,a} = L_{\infty}^j (1 - e^{-k_j a})$$

$$A_{j,a} = \begin{cases} A_{j,a} e^{-m_j} & \text{if } Size_{j,a} < L_{limit} \\ A_{j,a} e^{-m_j - f_j} & \text{if } Size_{j,a} > L_{limit} \end{cases}$$

$$C = \sum_{j=0}^{10} \sum_{a=0}^{360} \frac{f_j}{m_j + f_j} (1 - e^{-f_j + m_j}) w_{Size_{j,a}}^b A_{j,a}, \quad \forall Size_{j,a} > L_{limit}$$

$$e_j = \sum_{a=0}^{a=360} \alpha x^{\beta} A_{j,a} \quad \text{where } x = \begin{cases} Size_{j,a} & \text{if } Size_{j,a} > L_{maturity} \\ 0 & \text{if } Size_{j,a} < L_{maturity} \end{cases}$$

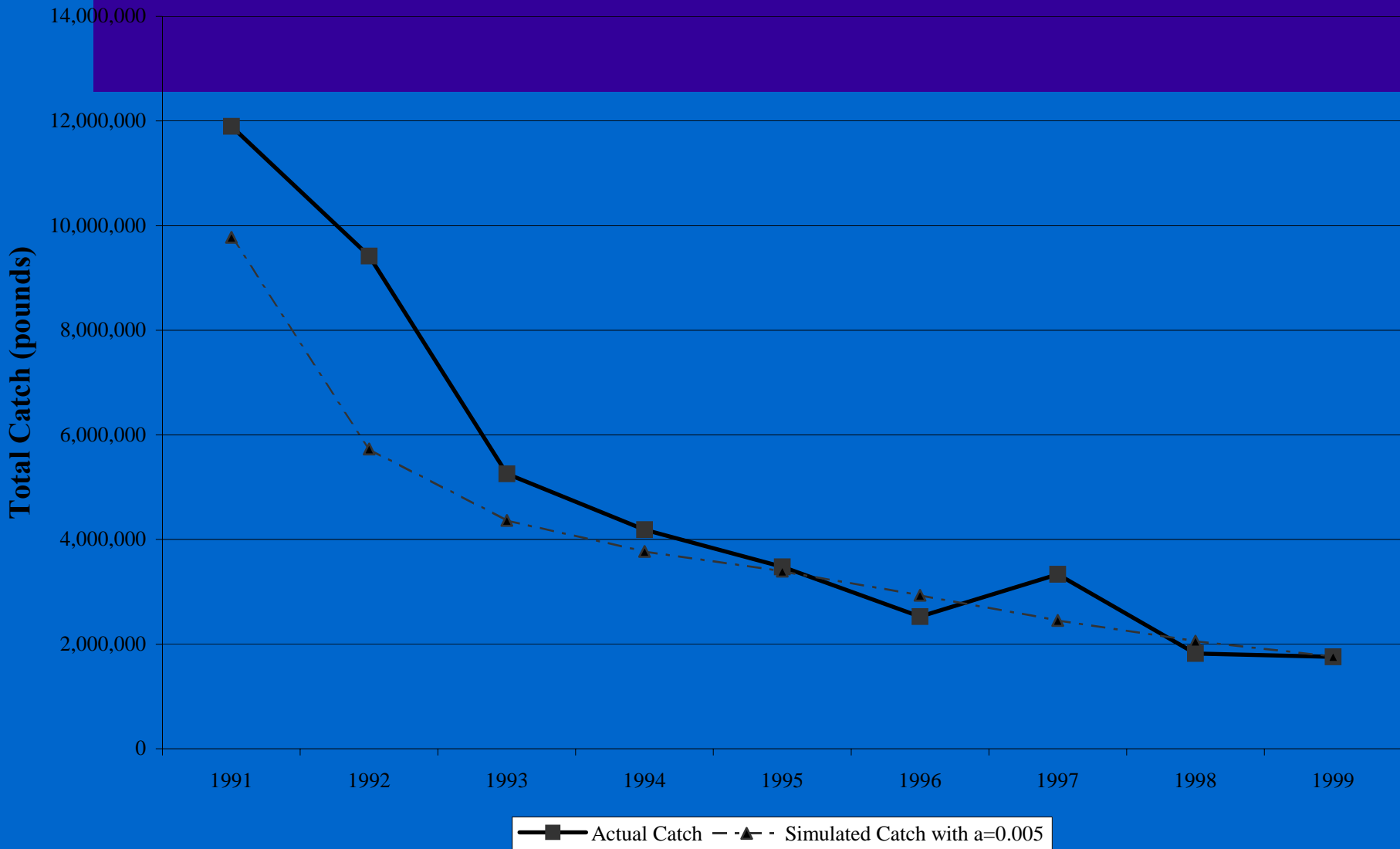
$$s^{in} = pDe$$

$$s_j^{out} = \frac{s_j^{in}}{a^{-1} + c^{-1} s_j^{in}}$$

# The Bioeconomic Link

$$f_{jt} = (Trips_{jt})hq = (o_t \sum_{p=1}^4 d_p p_{pjt})hq$$

# Calibration of Bioeconomic Simulation Model





## Appendix B



## Biological Parameter Values

# Parameter Values for Biological Model

From Botsford et al. (1993, 1994, 1999); Morgan (1997) and Morgan et al. (2000)

Parameter	Description	Value
k	growth	0.24
m	natural mortality	0.09
Linf	terminal size (mm)	118
Llimit	min. size limit (mm)	89
Lmature	min. size of sexually mature organism	60
f	fishing mortality	0.29
w	1st allometric weighting parm.	0.001413
b	2nd allometric weighting parm.	2.68
$\alpha$	1st egg production parm.	5.47E-06
$\beta$	2nd eggs production parm.	3.45
p	survival probability	1.0
a	resiliency settlement parm.	0.005 - 0.05
c	carrying capacity settlement parm.	1.2E+07 - 2.4E+07





## Appendix C



Details on the economic and  
biological literature

# Summary of Key Biological Articles

Article	Year	Citation Count	Modeling or Empirical	Pre- and Post-Reserve Effort Assumptions
Dugan and Davis	1993	74	Discussion	none
Polacheck	1990	49	Modeling	fixed total effort and uniform redistribution
Carr and Reed	1993	48	Modeling	constant harvest - no behavior
DeMartini	1993	45	Modeling	fixed total effort and uniform redistribution
Lauck et al.	1998	41	Modeling	random harvest fraction.
Russ and Alcala	1996	39	Empirical	N/A
Quinn et al.	1993	38	Modeling	fixed total effort and uniform redistribution, fishers give up at very low densities
Man et al.	1995	34	Modeling	fixed total effort and uniform redistribution
Bohnsack	1993	30	Discussion	N/A
Hastings and Botsford	1999	14	Modeling	fixed harvest fraction

## Economics Articles on Reserves

- Holland and Brazee (1996)
- Brown and Roughgarden (1997)
- Hanesson (1998)
- Sanchirico and Wilen (1999, 2001)
- Wilen, Smith, Lockwood and Botsford (2002)
- Smith (2002a, 2002b)
- Smith and Wilen (2002a, 2002b)